STRUCTURAL DESIGN - I

15. Design of Columns

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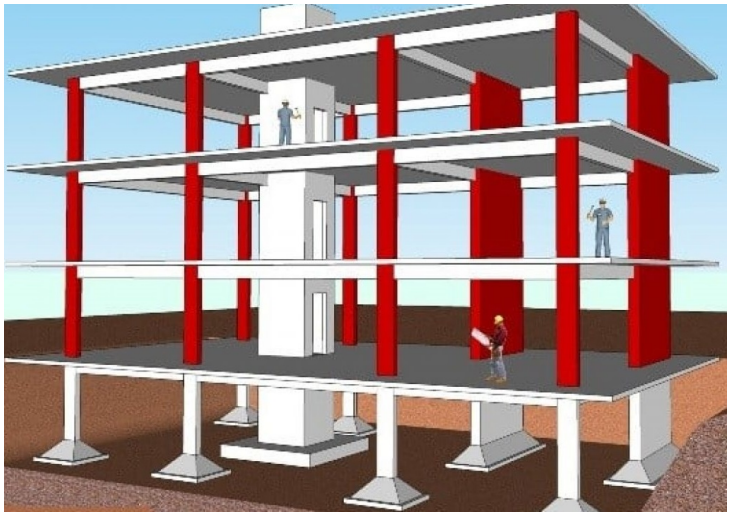
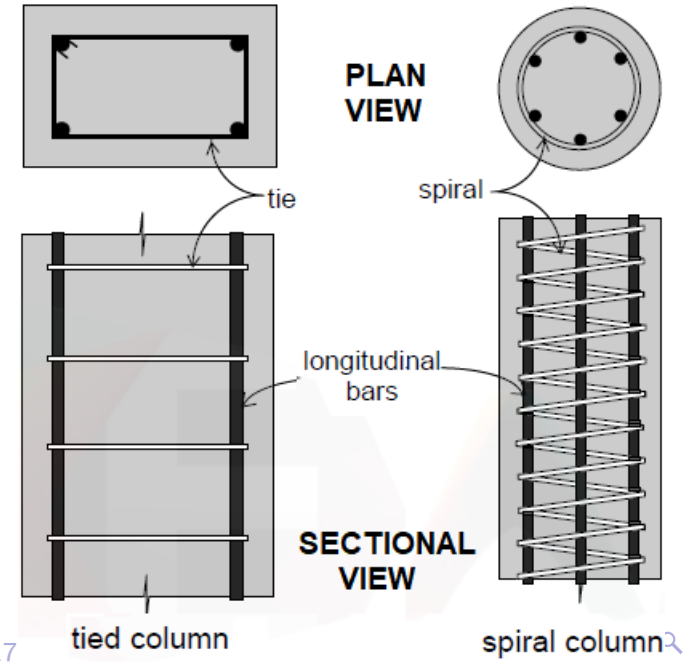
Columns or Compression Members

Definition:

- **Compression member** is a structural element which is mainly subjected to axial compressive force. It is defined under Cl. 25 (Page 41) of IS456. It is of 2 types:
  1. **Columns or Struts:**
     Effective length $>$ 3 x Least lateral dimension
  2. **Pedestals:**
     Effective length $<$ 3 x Least lateral dimension
- A column may be - *square, rectangular or circular* - in crossection.

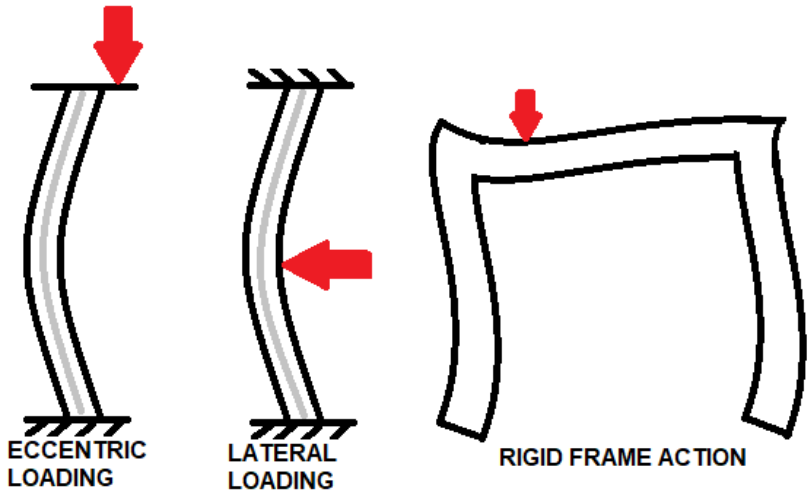




Columns or Compression Members

Loads on Columns:

- Most important load on column - **Axial Compressive Force**. But, Pure axial compression in columns is very rare.
- Generally, moment also accompanies axial force in columns, which may be due to:
  - eccentric loading.
  - lateral loading.
  - Rigid frame action due to monolithically cast beams or slabs.

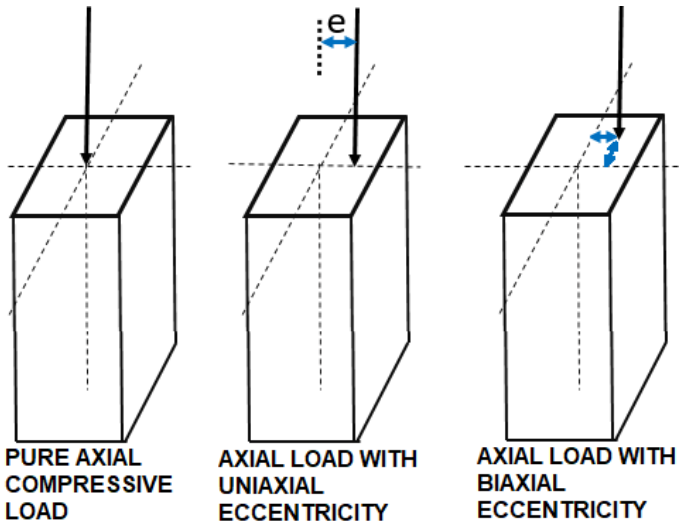


- Columns fail by - **crushing** or **buckling** - depending upon its length wrt its crosssectional dimensions.

Classification of Columns

Based on Type of Loading:

1. **Columns with Axial Load** or **(Concentric Load)**
   - very rare.
   - mostly, columns located at the interior of symmetrical buildings.
   - Even such columns should be capable to resist *minimum nominal eccentricities* (IS456 - Cl.25.4 - Page42)
2. **Columns with Eccentric Load** - Two types,
   - **Uniaxial eccentricity** - mostly, interior & exterior columns in buildings subj to lateral loads (WL & EL).
   - **Biaxial eccentricity** - mostly, columns located at building corners.



Classification of Columns

Based on Slenderness Ratio:

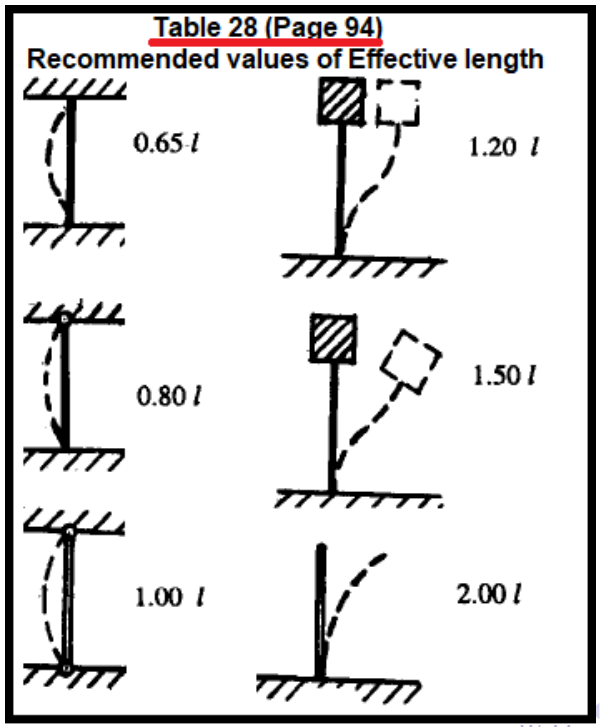
- **Slenderness Ratio** is a measure of vulnerability of a column to fail by buckling (or *elastic instability*)

$$Slenderness\ \ Ratio = \frac{Effective\ \ Length}{Least\ \ lateral\ \ dimension} = \frac{l_e}{D} = \frac{kl}{D}$$

where,

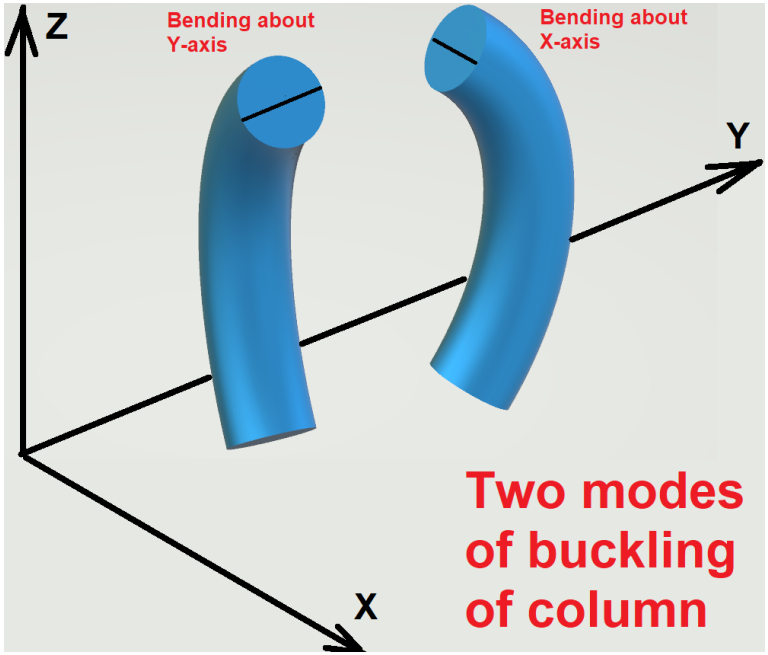
k = effective length ratio, obtained from Table28 of IS456

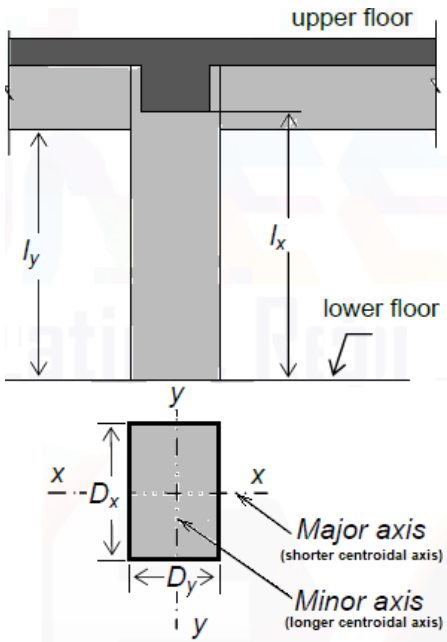
l = unsupported length of column = distance between lateral supports)



Classification of Columns

Based on Slenderness Ratio:





For the given rectangular column, there exist 2 slenderness ratios, one about each bending axis.

About Major axis, Slenderness Ratio = $\frac{l_{ex}}{D_x} = \frac{k_x l_x}{D_x}$

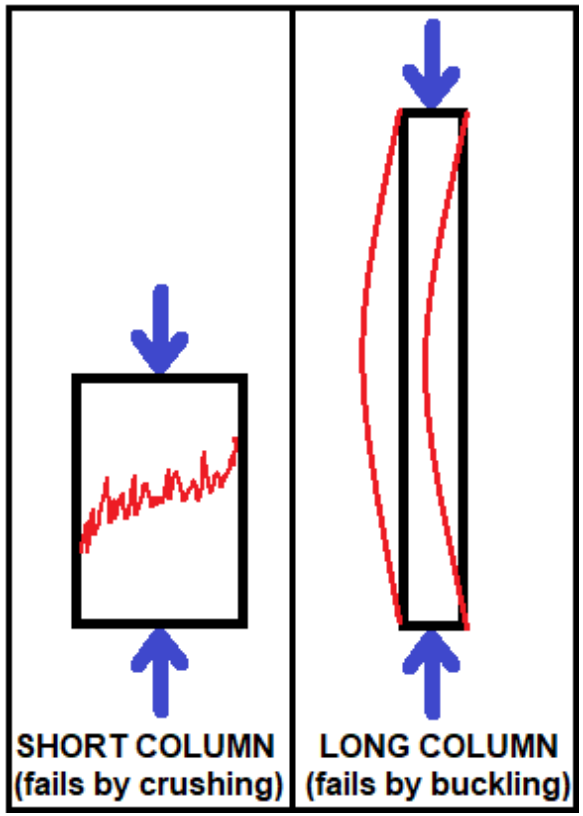
About Minor axis, Slenderness Ratio = $\frac{l_{ey}}{D_y} = \frac{k_y l_y}{D_y}$

Classification of Columns

Based on Slenderness Ratio:

Columns may be classified based on Slenderness Ratio, as follows:

1. **Short columns**
   - fail under ultimate loads, when material reaches ultimate strength.
   - if both slenderness ratios $\frac{l_{ex}}{D_x}$ and $\frac{l_{ey}}{D_y}$ should be < 12.
2. **Long columns (or slender columns)**
   - fail by buckling at lower compressive loads.
   - if any of slenderness ratios $\frac{l_{ex}}{D_x}$ or $\frac{l_{ey}}{D_y}$ > 12.



Codal Recommendations on Columns

Slenderness Limits:

25.3 Slenderness Limits for Columns

25.3.1 The unsupported length between end restraints shall not exceed 60 times the least lateral dimension of a column.

This means, for columns,

$$\frac{l}{D} \leq 60$$

25.3.2 If, in any given plane, one end of a column is unrestrained, its unsupported length, l, shall not exceed

$$\frac{100\,b^2}{D}.$$

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Codal Recommendations on Columns

Minimum Eccentricities:

25.4 Minimum Eccentricity Page 42

All columns shall be designed for minimum eccentricity, equal to the unsupported length of column/ 500 plus lateral dimensions/30, subject to a minimum of 20 mm. Where bi-axial bending is considered, it is sufficient to ensure that eccentricity exceeds the minimum about one axis at a time.

Hence, a column with rectangular section must be designed for the following minimum eccentricities about both axis

$$e_{x,\min} = \begin{cases} l/500 + D_x/30 \\ 20 \text{ mm} \end{cases} \text{(whichever is greater)}$$

$$e_{y,\min} = \begin{cases} l/500 + D_y/30 \\ 20 \text{ mm} \end{cases} \text{(whichever is greater)}$$

Codal Recommendations on Columns

Longitudinal Reinforcement:

26.5.3 *Columns*

26.5.3.1 *Longitudinal reinforcement* — Page 48

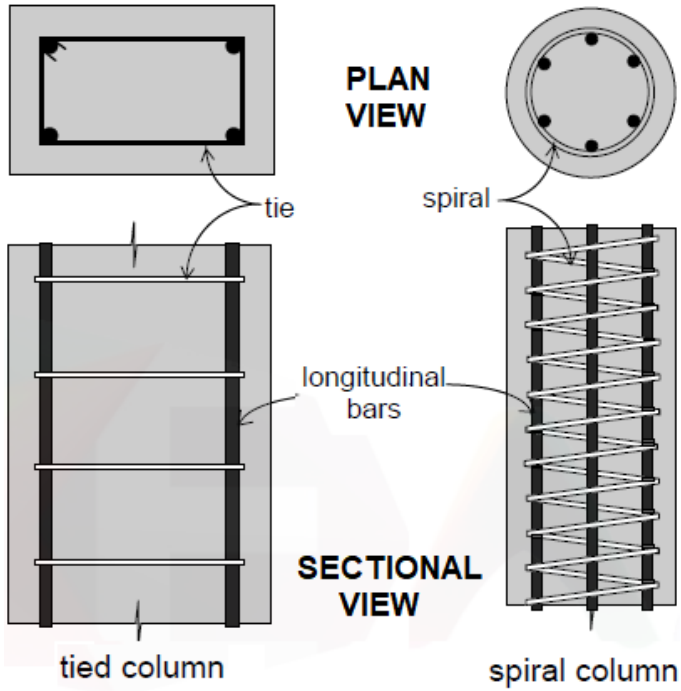
a) The cross-sectional area of longitudinal reinforcement, shall be not less than 0.8 percent nor more than 6 percent of the gross cross-sectional area of the column.

NOTE — The use of 6 percent reinforcement may involve practical difficulties in placing and compacting of concrete; hence lower percentage is recommended. Where bars from the columns below have to be lapped with those in the column under consideration, the percentage of steel shall usually not exceed 4 percent.

c) The minimum number of longitudinal bars provided in a column shall be four in rectangular columns and six in circular columns.

d) The bars shall not be less than 12 mm in diameter.

g) Spacing of longitudinal bars measured along the periphery of the column shall not exceed 300 mm.



Codal Recommendations on Columns

Clear cover to Reinforcement:

Table 16A
Nominal Cover to Meet Specified Period of Fire Resistance
(*Clauses* 21.4 *and* 26.4.3 and *Fig.* 1)

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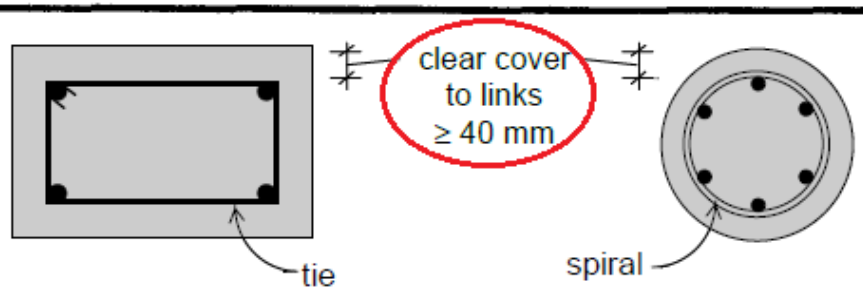
Fire Resistance	Nominal Cover						
	Beams		Slabs		Ribs		Columns
	Simply supported	Continuous	Simply supported	Continuous	Simply supported	Continuous	
h	mm	mm	mm	mm	mm	mm	mm
0.5	20	20	20	20	20	20	40
1	20	20	20	20	20	20	40
1.5	20	20	25	20	35	20	40
2	40	30	35	25	45	35	40
3	60	40	45	35	55	45	40
4	70	50	55	45	65	55	40



Codal Recommendations on Columns

Transverse Reinforcement:

Transverse reinforcements must enclose all longitudinal bars in a column, to:

- confine concrete, thereby improving its strength.
- hold the longitudinal bars in position and prevent it from buckling.
- enhance the shear torsional resistance of column.

26.5.3.2 *Transverse reinforcement*

a) *General*—A reinforced concrete compression member shall have transverse or helical reinforcement so disposed that every longitudinal bar nearest to the compression face has effective lateral support against buckling subject to provisions in (b). The effective lateral support is given by transverse reinforcement either in the form of circular rings capable of taking up circumferential tension or by polygonal links (lateral ties) with internal angles not exceeding 135°. The ends of the transverse reinforcement shall be properly anchored [*see* **26.2.2.4** (b)].

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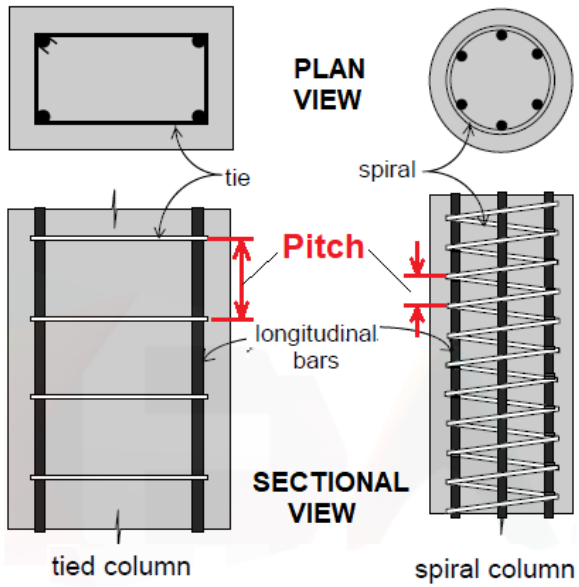

c) *Pitch and diameter of lateral ties*

1) *Pitch*—The pitch of transverse reinforcement shall be not more than the least of the following distances:

Max. Pitch

i) The least lateral dimension of the compression members;

ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied; and

iii) 300 mm.

2) *Diameter*—The diameter of the polygonal links or lateral ties shall be not less than one-fourth of the diameter of the largest longitudinal bar and in no case less than 6 mm.

Min. Dia

d) *Helical reinforcement*

1) *Pitch*—Helical reinforcement shall be of regular formation with the turns of the helix spaced evenly and its ends shall be anchored properly by providing one and a half extra turns of the spiral bar. Where an increased load on the column on the strength of the helical reinforcement is allowed for, the pitch of helical turns shall be not more than 75 mm, nor more than one-sixth of the core diameter of the column, nor less than 25 mm, nor less than three times the diameter of the steel bar forming the helix. In other cases, the requirements of **26.5.3.2** shall be complied with.

Max. Pitch

Min. Pitch

2) The diameter of the helical reinforcement shall be in accordance with **26.5.3.2** (c) (2).

Min Dia

Limit State Design of Short columns

Assumptions:

39 LIMIT STATE OF COLLAPSE : COMPRESSION

39.1 Assumptions

Page 70

In addition to the assumptions given in **38.1** (a) to **38.1** (e) for flexure, the following shall be assumed:

a) The maximum compressive strain in concrete in axial compression is taken as 0.002.

b) The maximum compressive strain at the highly compressed extreme fibre in concrete subjected to axial compression and bending and when there is no tension on the section shall be 0.003 5 minus 0.75 times the strain at the least compressed extreme fibre.

In addition to the assumptions in the Limit state of Collapse in Flexure

Limit State Design of Short columns

Design of Columns with Axial Load:

The design load on column is obtained as:

39.3 Short Axially Loaded Members in Compression Page 71

The member shall be designed by considering the assumptions given in **39.1** and the minimum eccentricity. When the minimum eccentricity as per **25.4** does not exceed 0.05 times the lateral dimension, the members may be designed by the following equation:

$$P_u = 0.4 f_{ck} . A_c + 0.67 f_y . A_{sc}$$

where

P_u = axial load on the member,

f_{ck} = characteristic compressive strength of the concrete,

A_c = Area of concrete,

f_y = characteristic strength of the compression reinforcement, and

A_{sc} = area of longitudinal reinforcement for columns.

39.4 Compression Members with Helical Reinforcement

The strength of compression members with helical reinforcement satisfying the requirement of **39.4.1** shall be taken as 1.05 times the strength of similar member with lateral ties.

Limit State Design of Short columns

Design of Columns with Uniaxial Eccentric Load:

Interaction diagrams from SP16 is used for the design of short columns with uniaxial eccentric compressive load.

- Charts 27 - 38: for rectangular sections with reinforcement distributed equally on two sides.
- Charts 39 - 50: for rectangular sections with reinforcement distributed equally on four sides.
- Charts 51 - 62: for circular sections.

Now solve numerical examples!!!